

Scientific Overview

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Background

- Members of the U.S. Lattice Gauge Theory Community have been working together for the last six years to create the computational infrastructure needed to study quantum chromodynamics (QCD).
- Nearly all high energy and nuclear physicists in the U.S. who work on lattice QCD are participating. The infrastructure will be available to all.
- Three DOE laboratories are playing critical roles:
 - Brookhaven National Laboratory
 - Fermi National Accelerator Center
 - Thomas Jefferson National Accelerator Facility
- The Lattice QCD Computing Project is the culmination of this effort.

Supporting Projects

- Development of community software for efficient use of terascale computers. (SciDAC Grant)
- Construction and operation of prototype commodity clusters optimized for QCD at FNAL and JLab. (SciDAC Grant)
- Construction of a 12,288 QCDOC computer at BNL. (Funded by ASCR, HEP, NP)
- Software development and hardware R & D will continue for at least another year under the Lattice QCD SciDAC grant.

Alignment with DOE Strategic Plan

- DOE's Science Strategic Goal: To protect our national and economic security by providing world-class scientific research capacity and advancing scientific knowledge.
- The mission of the High Energy Physics Program is to explore and to discover the laws of nature as they apply to the basic constituents of matter and the forces between them.
- The mission of the Nuclear Physics Program is to foster fundamental research in nuclear physics that will provide new insights and advance our knowledge on the nature of matter and energy . . .

The Standard Model

- The Standard Model consists of two components:
 - The Weinberg–Salam theory of weak and electromagnetic interactions.
 - Quantum Chromodynamics, the theory of the strong interactions.
- The Standard Model has been enormously successful. However, it has proven very difficult to extract many of the predictions of QCD. To do so requires large scale numerical simulations within the framework of lattice gauge theory.
- The objectives of these simulations are to fully understand the physical phenomena encompassed by QCD, and to make precise calculations of the theory's predictions.

Impact on Experimental Programs

- Major goals of the DOE's experimental programs in high energy and nuclear physics on which lattice QCD simulations will have an important impact are to:
 - Make precise tests of the Standard Model.
 - Determine the properties of strongly interacting matter under extreme conditions.
 - Understand the internal structure of nucleons and other strongly interacting particles.
- Lattice QCD calculations are essential to research in all of these areas.

Impact on CKM Matrix Elements

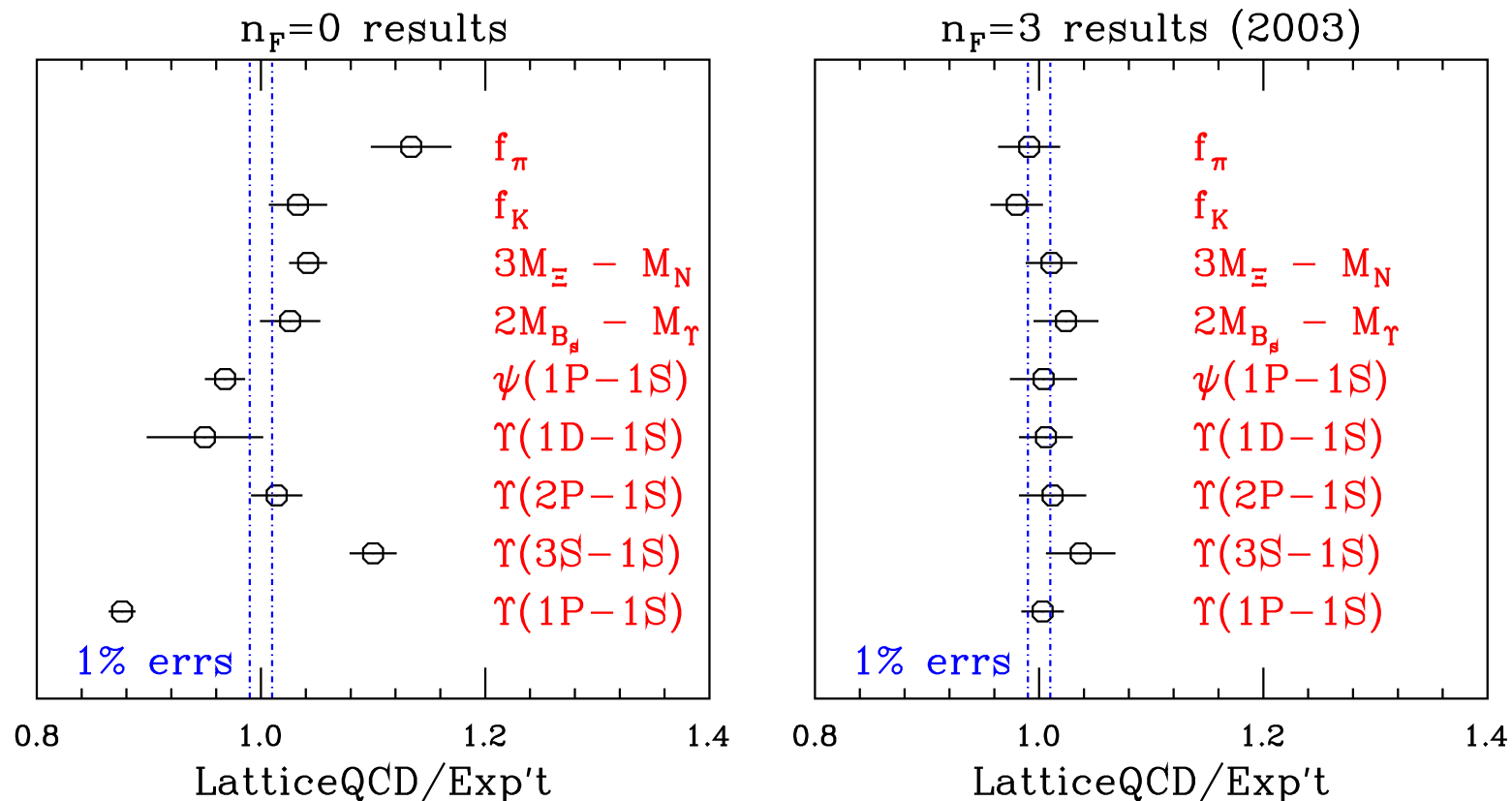
Measurement	CKM Matrix Element	Hadronic Matrix Element	Non-Lattice Errors	Lattice Errors 2004	Lattice Errors 0.6 TF-Yr	Lattice Errors 6.0 TF-Yr	Lattice Errors 60. TF-Yr
ε_K ($\bar{K}K$ mixing)	$\text{Im } V_{td}^2$	\hat{B}_K	10%	20%	12%	5%	3%
ΔM_d ($\bar{B}B$ mixing)	$ V_{td} ^2$	$f_{B_d}^2 B_{B_d}$	6%	30%	16%–26%	8%–10%	6%–8%
$\Delta M_d / \Delta M_s$	$ V_{td} / V_{ts} ^2$	ξ^2	—	12%	8%	6%	3%–4%
$B \rightarrow (\rho_\pi) l \nu$	$ V_{ub} ^2$	$\langle \rho_\pi (V - A)_\mu B \rangle^2$	7%	15%	10%–13%	5.5%–6.5%	4%–5%
$B \rightarrow (D_D^*) l \nu$	$ V_{cb} ^2$	$ \mathcal{F}_{B \rightarrow (D_D^*) l \nu} ^2$	2%	4.4%	3%–4%	1.8%–2%	1%–1.4%

The impact of improved lattice QCD calculations on the determination of CKM matrix elements. The error estimates are from the Lattice QCD Executive Committee Whitepaper (2004).

Future Prospects

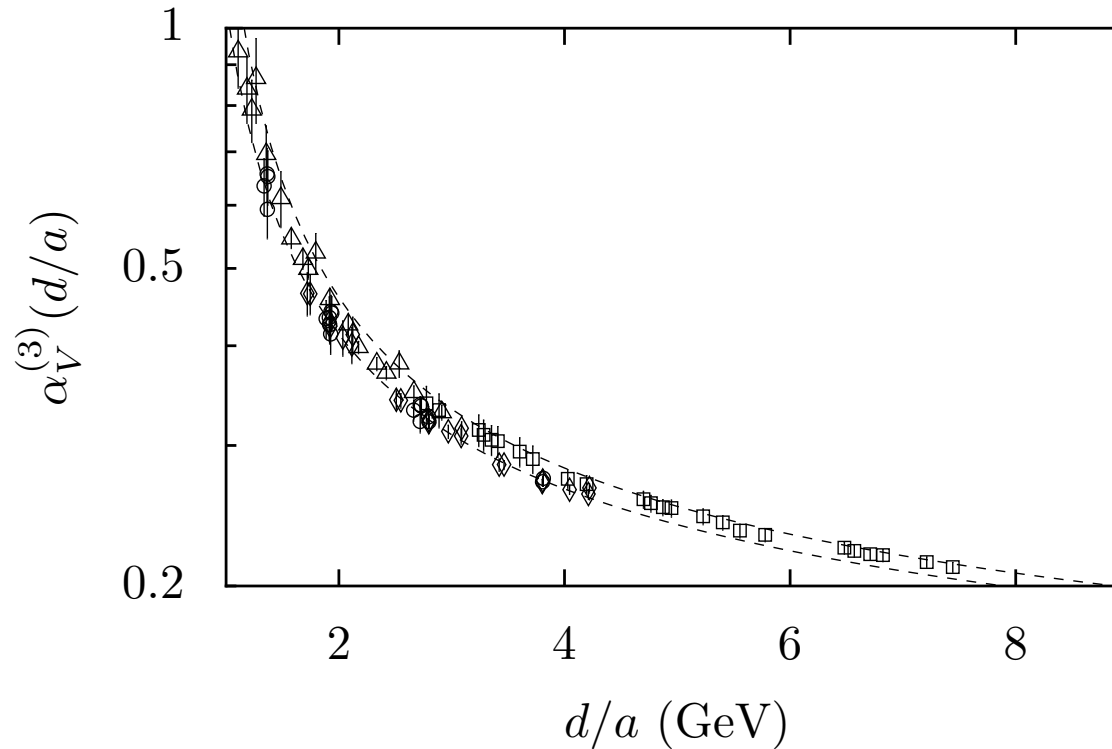
- Important advances are expected in the next few years due to:
 - Increases in computing power
 - Improvements in algorithms
 - Improved formulations of QCD on the lattice
 - Improved staggered quarks (Asqtad)
 - Domain wall quarks
- U.S. lattice gauge theorists need to take advantage of the opportunities provided by these developments in order to support the experimental programs in a timely fashion and to maintain international leadership on our field.

Impact of Sea Quarks



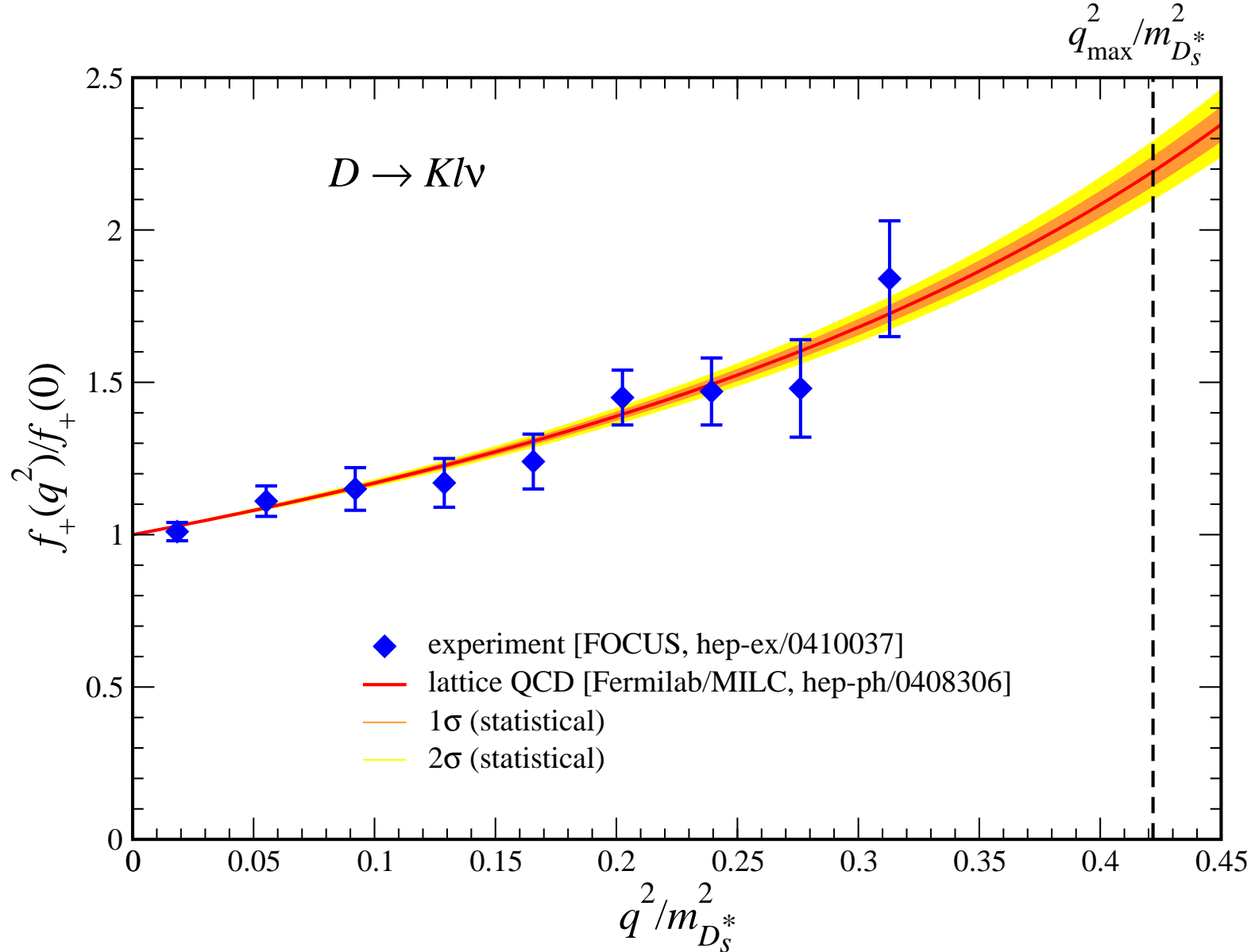
Results of the Fermilab Lattice, HPQCD, MILC and UKQCD Collaborations

The Strong Coupling Constant



$$\alpha^{\overline{\text{MS}}}(m_Z) = 1177(13) \quad \text{HPQCD, UKQCD} - \text{Lattice}$$
$$\alpha^{\overline{\text{MS}}}(m_Z) = 1187(20) \quad \text{Particle Data Group} - \text{Expt.}$$

Semileptonic Decay of the D Meson



Validation of Scientific Importance

- Award of a grant from the DOE SciDAC Program (2001). Grant renewed in (2004).
- Review by the Wilczek Panel (2003)
 - “The scientific merit of the suggested program is very clearly outstanding.”
 - “Both the proposers and the DOE should recognize that this is an endeavor that is not likely to be exhausted in 4 years or even in 10.”
- The Nuclear Science Advisory Committee (2003) and the High Energy Physics Advisory Panel (2004) have both recommended substantial DOE investments in hardware for Lattice QCD.

Conclusion

- This project will enable major advances in our understanding of the fundamental forces of nature.
- It is squarely aligned with the missions of the High Energy Physics and Nuclear Physics Programs.